Antineutrino Running at MiniBooNE

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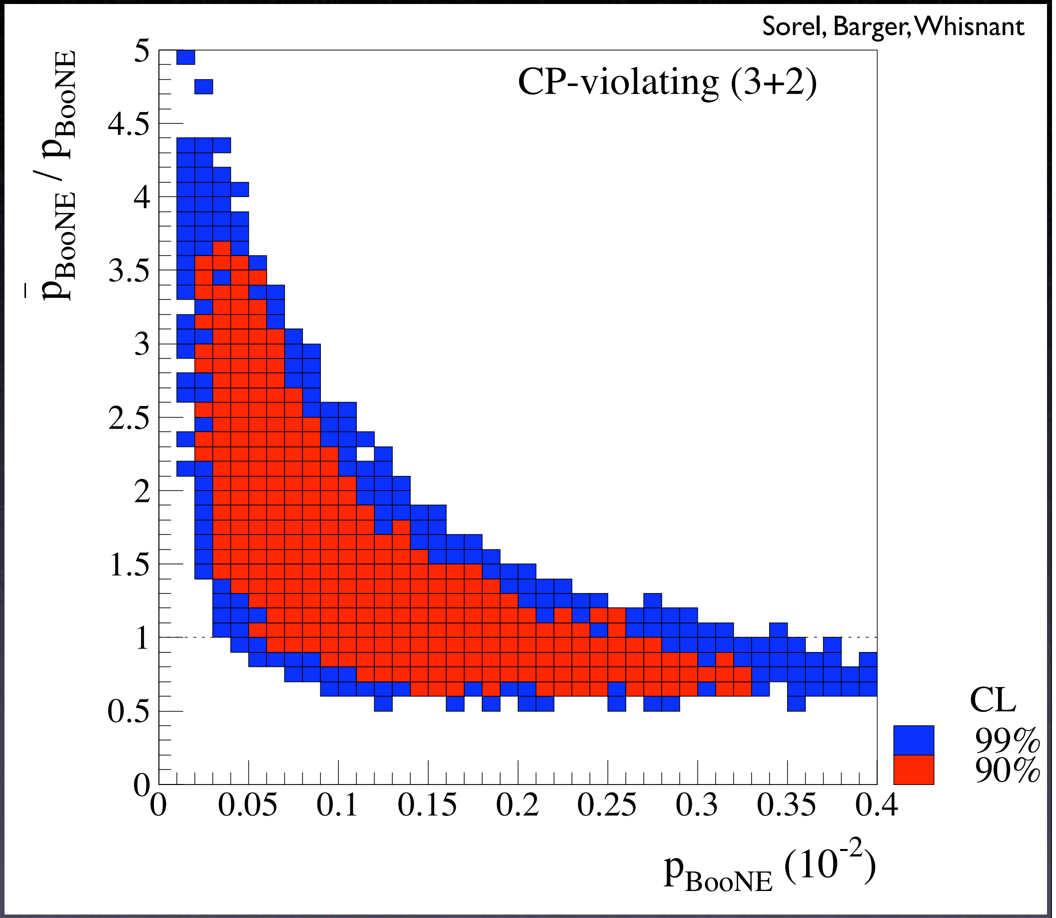
Motivation

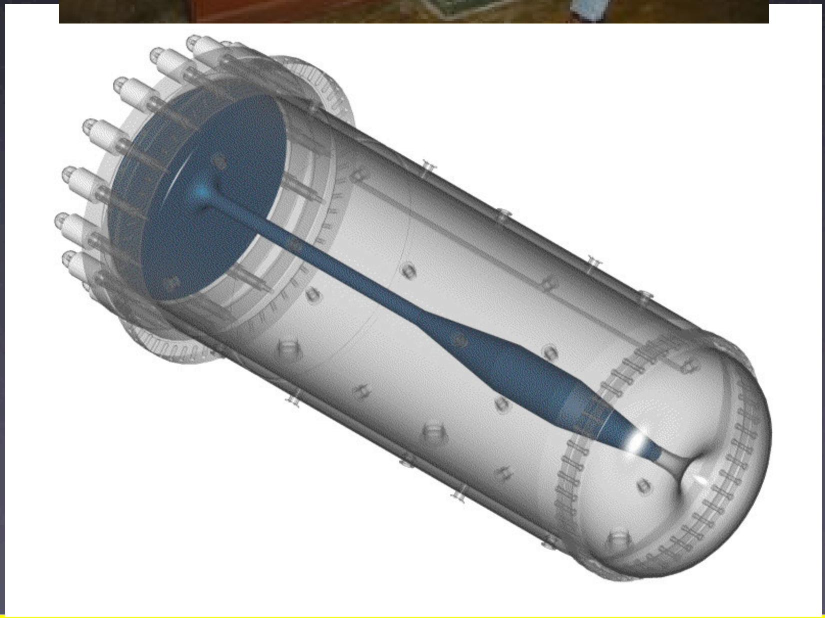
- $\bar{\nu}$ running is a subject of much interest
- CP violation in ν sector
- Difference in oscillation probabilities for $\nu, \bar{\nu}$
- Major experimental obstacles:
  - $\bar{\nu}$ cross sections not well known
  - wrong sign backgrounds
    - ν in a $\bar{\nu}$ beam



Asymmetry of $\bar{\nu}$,ν oscillation probabilities in MiniBooNE verus ν oscillation prob.

Outline

- Focus on WS BGs
- What MiniBooNE can do with one year of antineutrino running
  - 2.0E20 POT total
  - Cross section physics
  - Oscillations
- http://www-boone.fnal.gov/publicpages/loi.ps.gz
- Window of opportunity for a near detector in the Booster Neutrino Beam:
  - SciBar detector
- http://home.fnal.gov/~wascko/scibar.pdf



Images of the MiniBooNE horn

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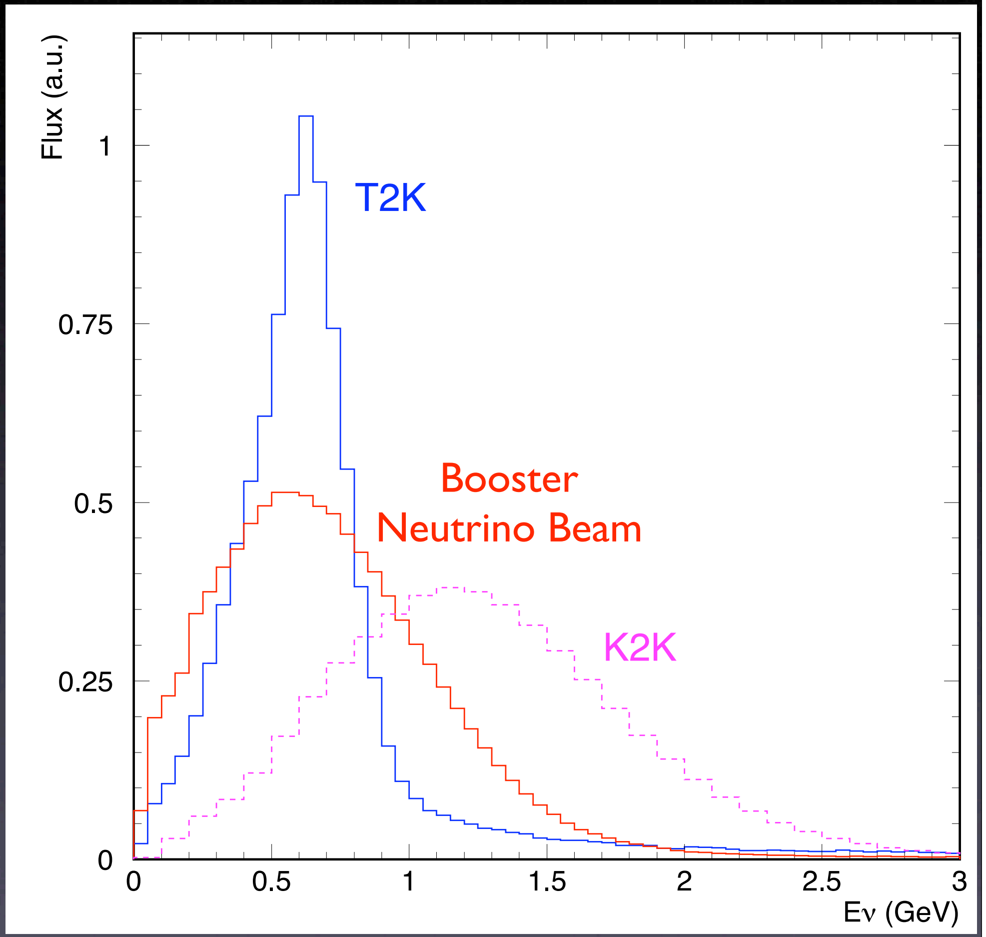
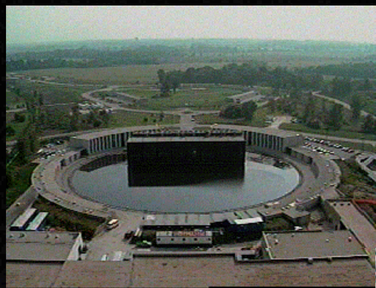
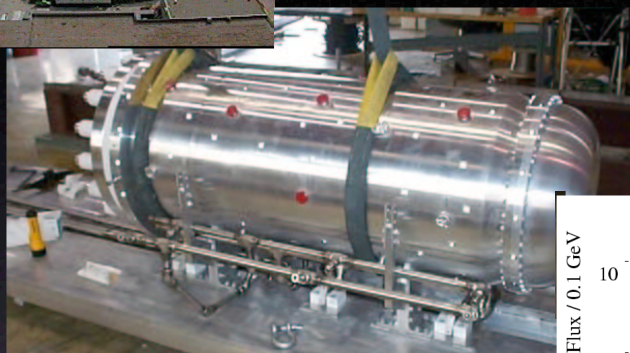


Comparison of ν_μ fluxes



Extract 8 GeV protons from Fermilab Booster

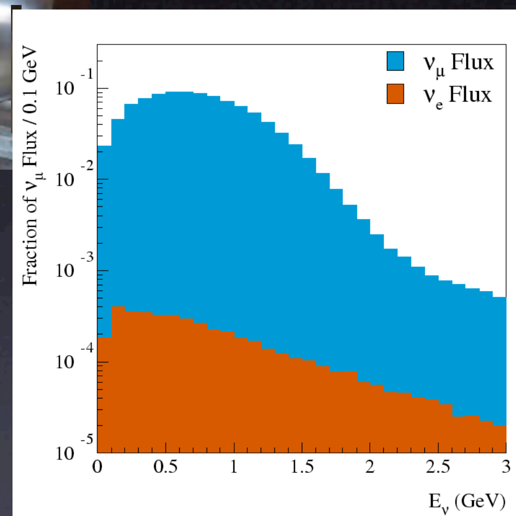
1.7 λ beryllium target (HARP results soon!)



Reversible magnetic horn

Focusses mesons of specific charge

Allows antineutrino running!



50 m decay region

>99% muon neutrinos

both ν and $\bar{\nu}$

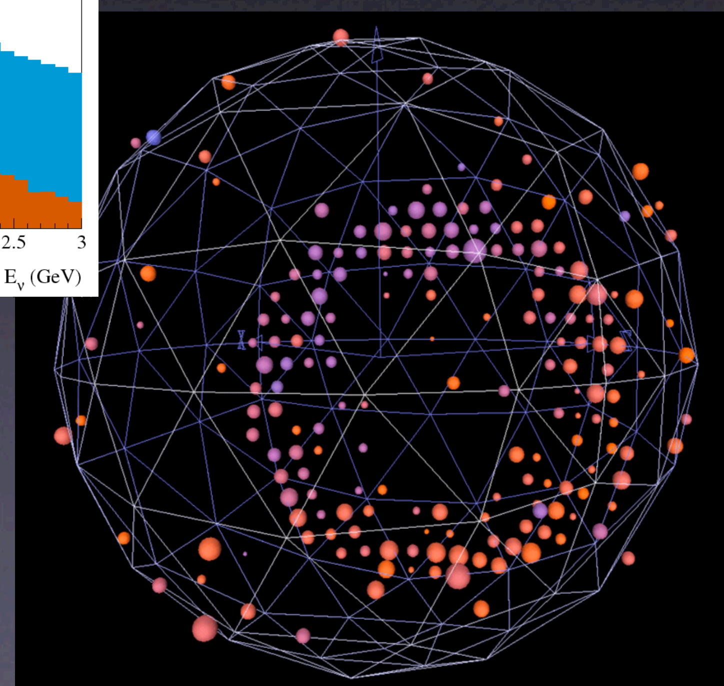
490 m dirt

800 ton CH_2 detector

1520 PMTs

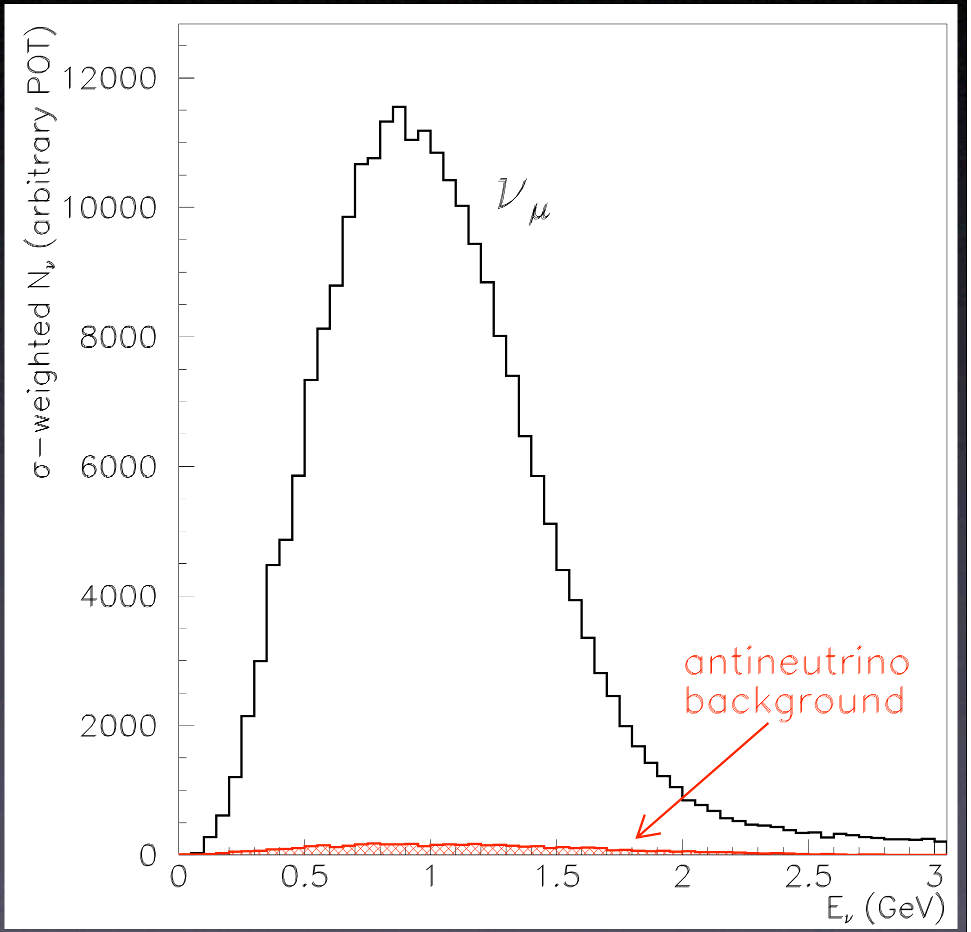
1280 in main tank

240 in veto region



Wrong Sign BGs

- In neutrino running, wrong sign backgrounds are very small (2%)
- In antineutrino running they are much larger (30%)
- Cherenkov calorimeters cannot distinguish μ^- from μ^+
- Need a way to extract the WS BGs!



Wrong Sign BGs

- In neutrino running, wrong sign backgrounds are very small (2%)
- In antineutrino running they are much larger (30%)
- Cherenkov calorimeters cannot distinguish μ^- from μ^+ (event by event)
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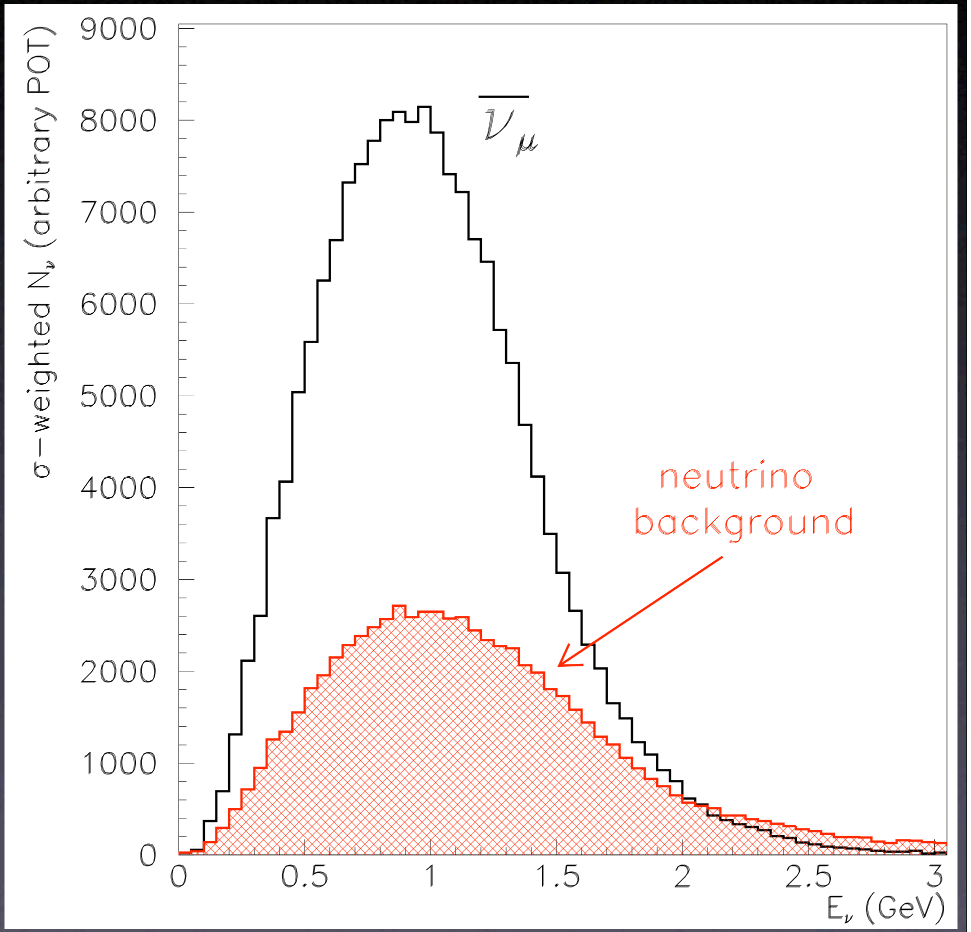
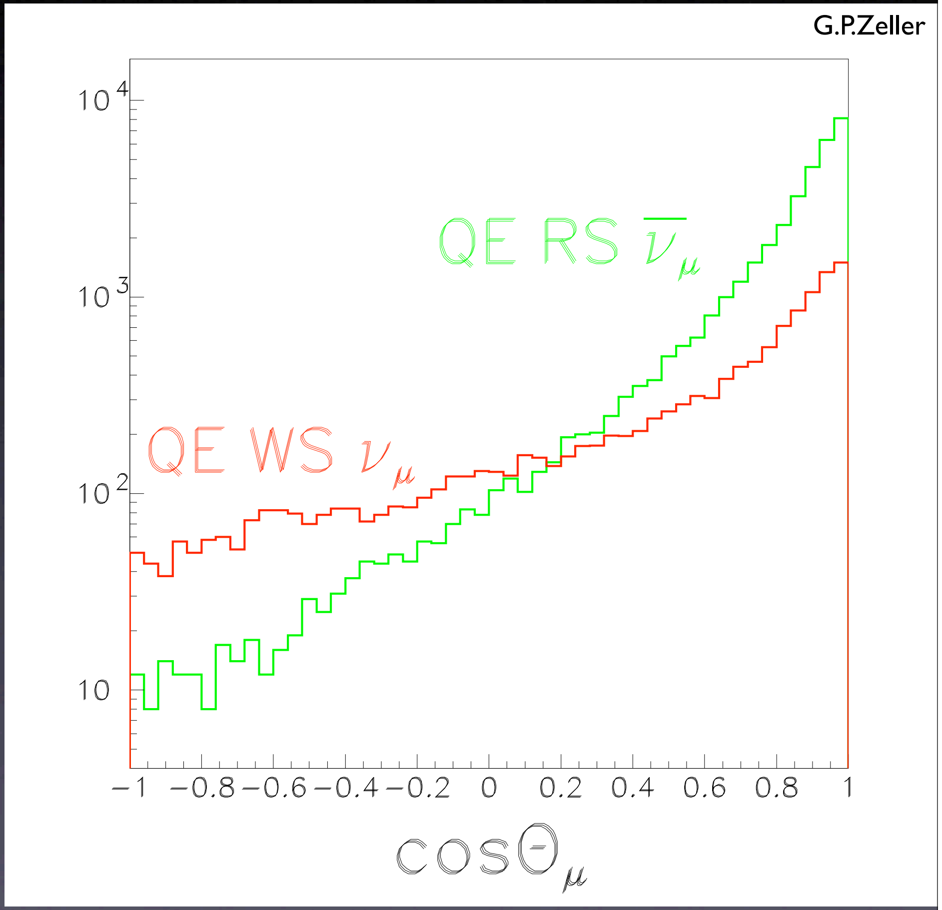


Constraining WS BGs

- MiniBooNE has developed three methods of constraining the overall fraction of $\nu, \bar{\nu}$
  - μ direction
  - μ lifetime
  - $CC1\pi^+$ event selection
- Independent constraints
- Sensitive to total WS fraction
  - Not sensitive to energy spectrum of WS events

WS BG Constraints: μ Direction

- Softer Q^2 spectrum for antineutrino events means more forward-peaked μ
- Can fit angular distribution shape and extract RS/WS fractions
- Using generated muon directions, can extract WS fraction with 5% uncertainty



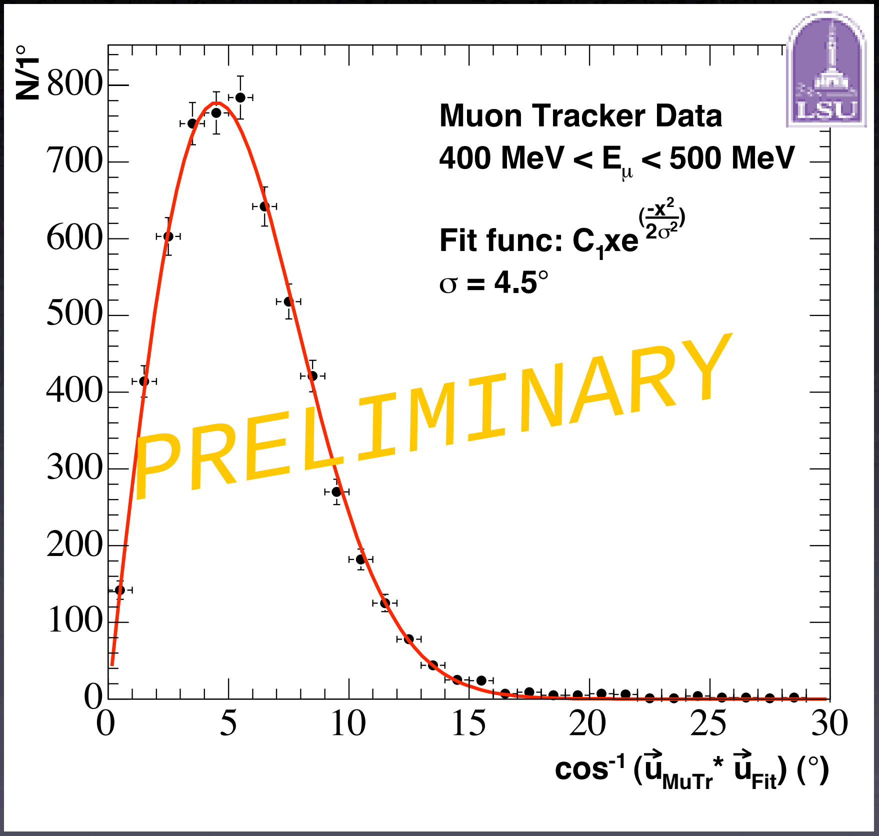
WS BG Constraints:
μ Direction

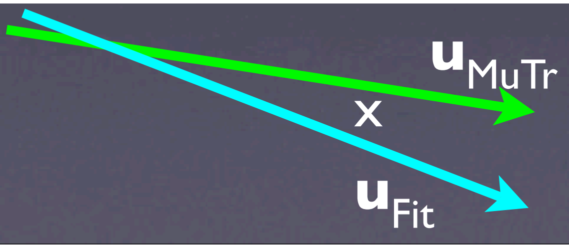
- MiniBooNE has very good angular reconstruction for muons
- Tested with cosmic muon calibration system
- Fit distribution of

$$\cos^{-1}(\vec{u}_{MuTr} \cdot \vec{u}_{Fit})$$

$$xe^{-x^2/2\sigma^2}$$

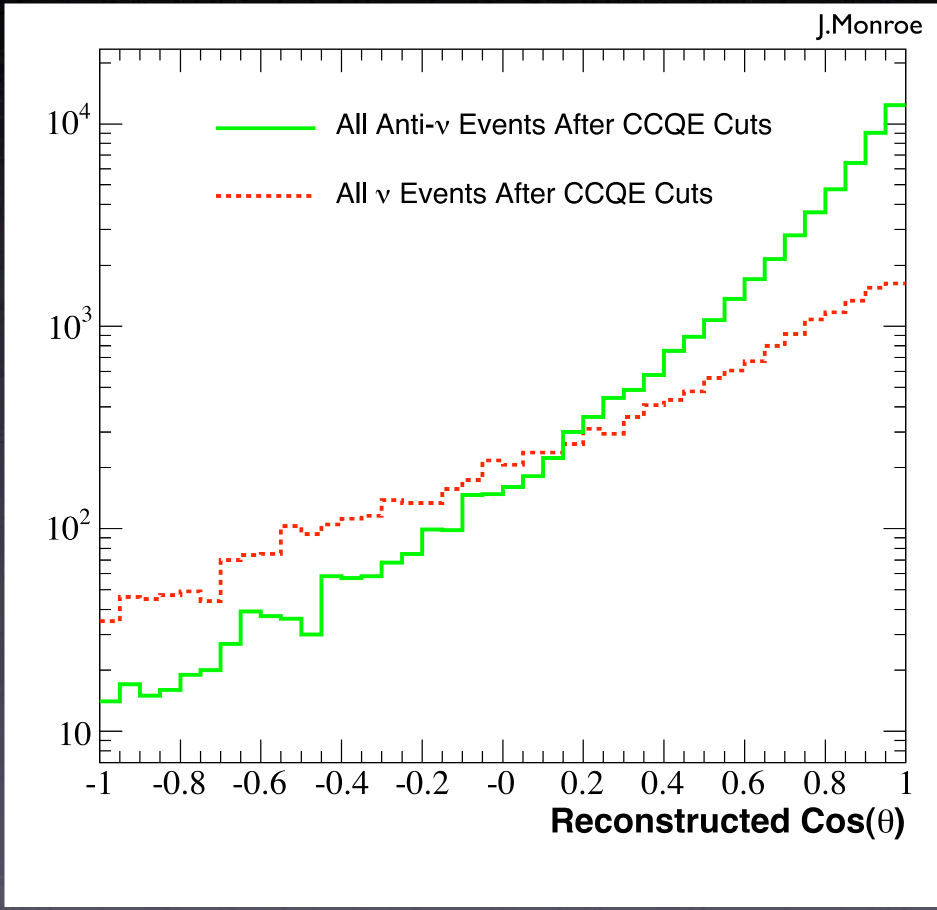
  - (projection of a 2D Gaussian)
  - Account for intrinsic resolution of muon tracker
- Angular resolution = 4.0° at 400-500 MeV





WS BG Constraints: μ Directions

- Reconstruction has little effect on this constraint
- WS fraction can be measured to 7% with reconstructed angles
- Can also use Q^2 distributions
  - Similar precision
    - Stronger constraint
    - Poorer resolution
    - Larger uncertainties (currently)



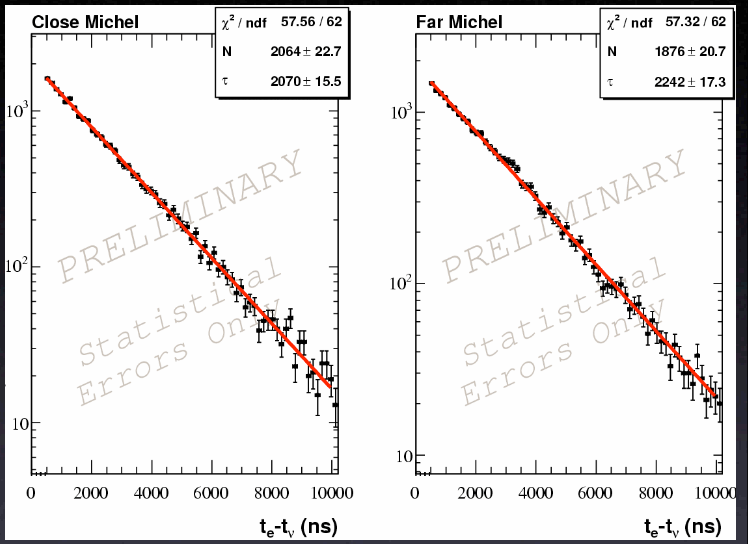
WS BG Constraints: $CC1\pi^+$ Selection

- Use CC1π+ event selection:
- Tag $\nu_\mu C \rightarrow \mu^- \pi^+ X$ events with two Michel electrons
- π- absorbed by carbon, do not decay
  - Cannot tag $\bar{\nu}_\mu C \rightarrow \mu^+ \pi^- X$ events: only 1 Michel
- Two Michel sample is 85% pure WS
- Constrain WS fraction with 15% uncertainty

Neutrino type	# before cuts	# after cuts
ν_μ (WS)	30,539	2,525
$\bar{\nu}_\mu$ (RS)	71,547	461
Total	102,086	2,986

WS BG Constraints:
μ Lifetime

- Use muon decay rate in mineral oil to constrain WS BGs
- 8% μ- capture probability on carbon
  - $\tau_{\mu-}$=2.026μs, $\tau_{\mu+}$=2.197μs
- Can extract WS contribution with 30% uncertainty
- Independent of kinematics and reconstruction



μ^- lifetime μ^+ lifetime

Comparison of muon lifetimes from CC1π^+ data sample

WS BG Constraints: Summary

Measurement	WS uncertainty	resultant $\bar{\nu}_\mu$ σ error
$\cos\vartheta_\mu$	7%	2%
$CC1\pi^+$	15%	5%
μ Lifetimes	30%	9%

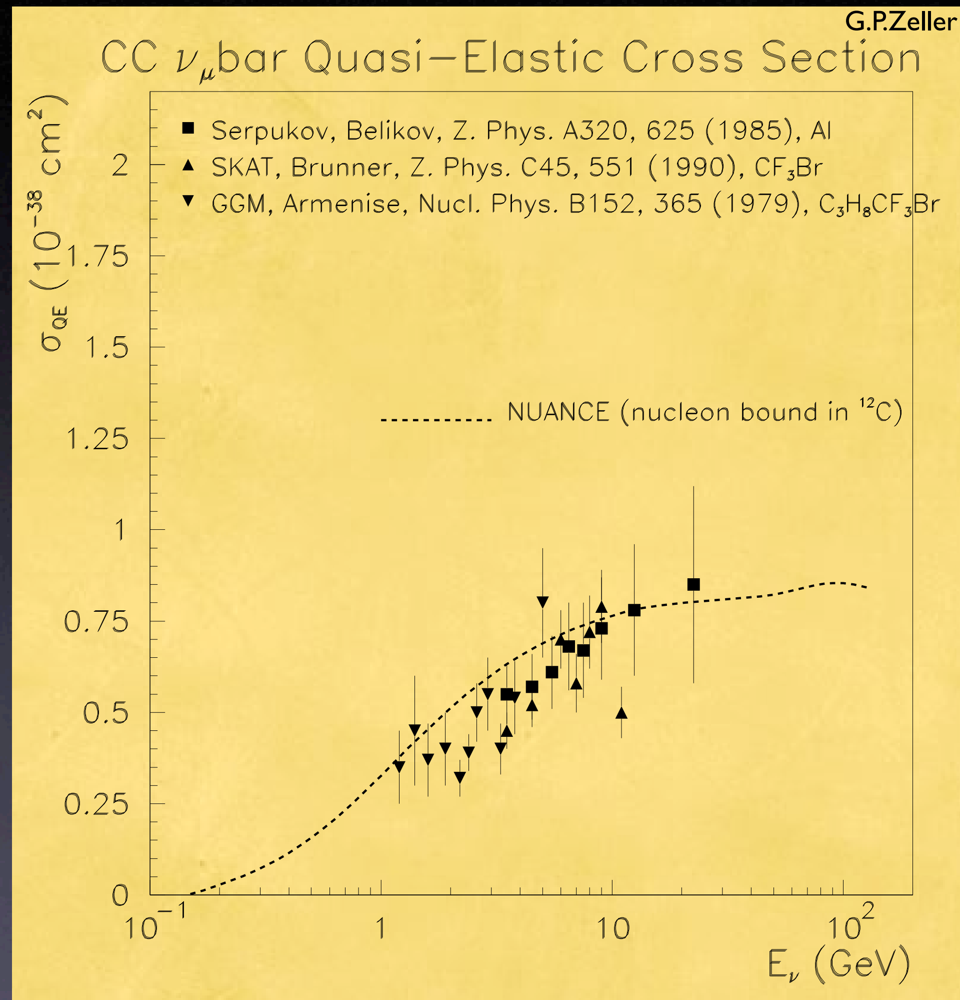
Note can only measure overall rate of WS BGs, not energy spectrum

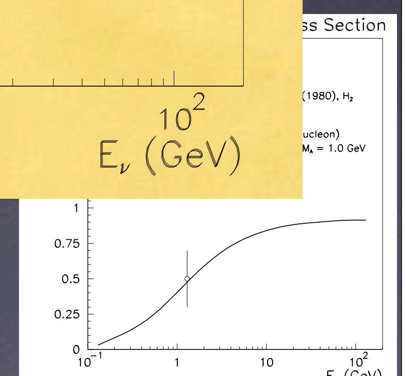
Status of $\bar{\nu}_\mu$ σs

- Very few data, especially at low energy
- Not much understanding of nuclear targets
- $\bar{\nu}_\mu$ CCQE
  - ~1700 events
- $\bar{\nu}_\mu$ $NC\pi^0$
  - Only one (1) measurement ever.
- $\bar{\nu}_\mu$ $CC1\pi^-$
  - ~1300 events

$\bar{\nu}_\mu$ CC QE Scattering

- Few $\bar{\nu}_\mu$ QE measurements
- None below 1 GeV
- MiniBooNE expects ~40,000 CCQE interactions before cuts for 2E20 POT





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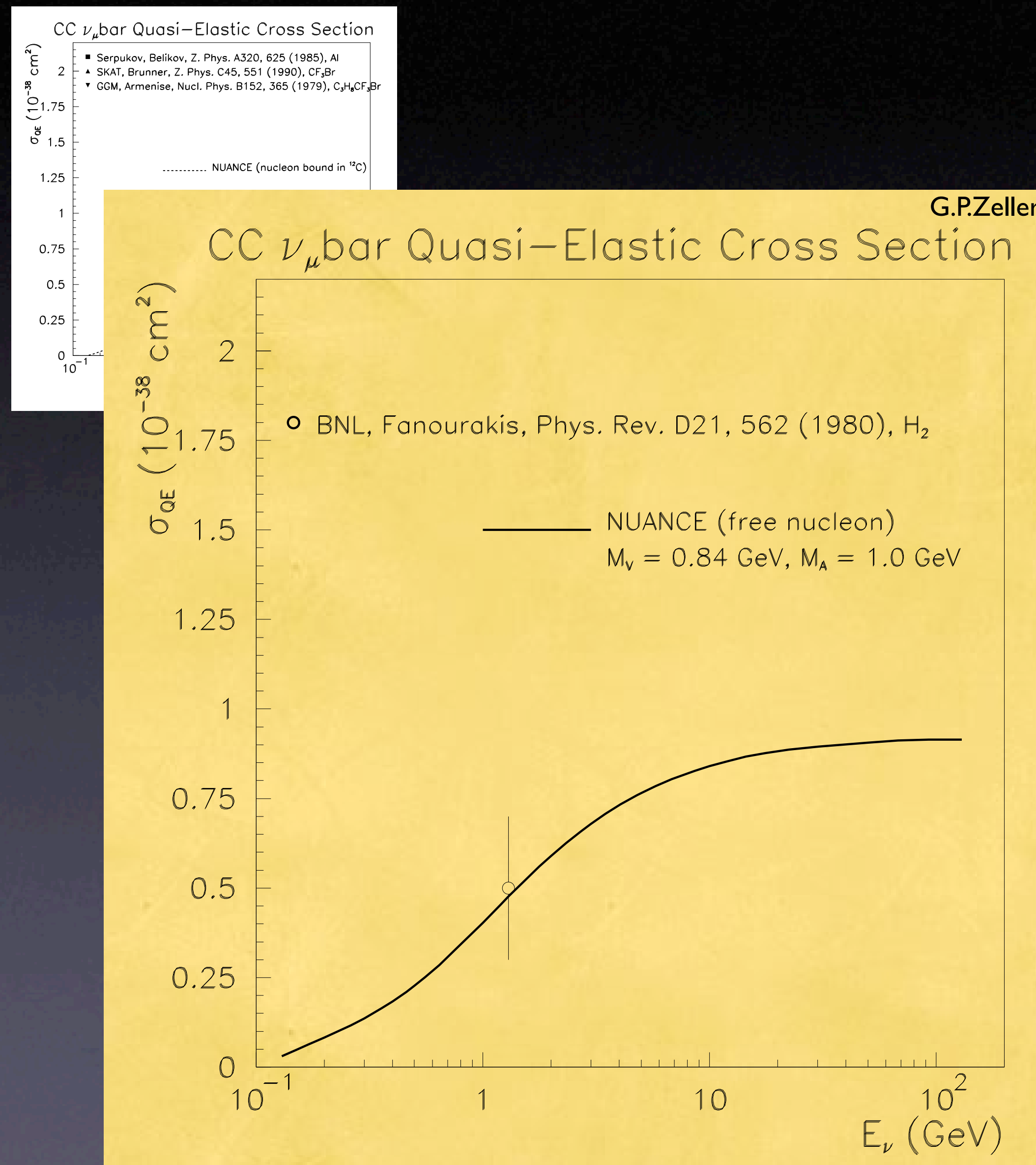
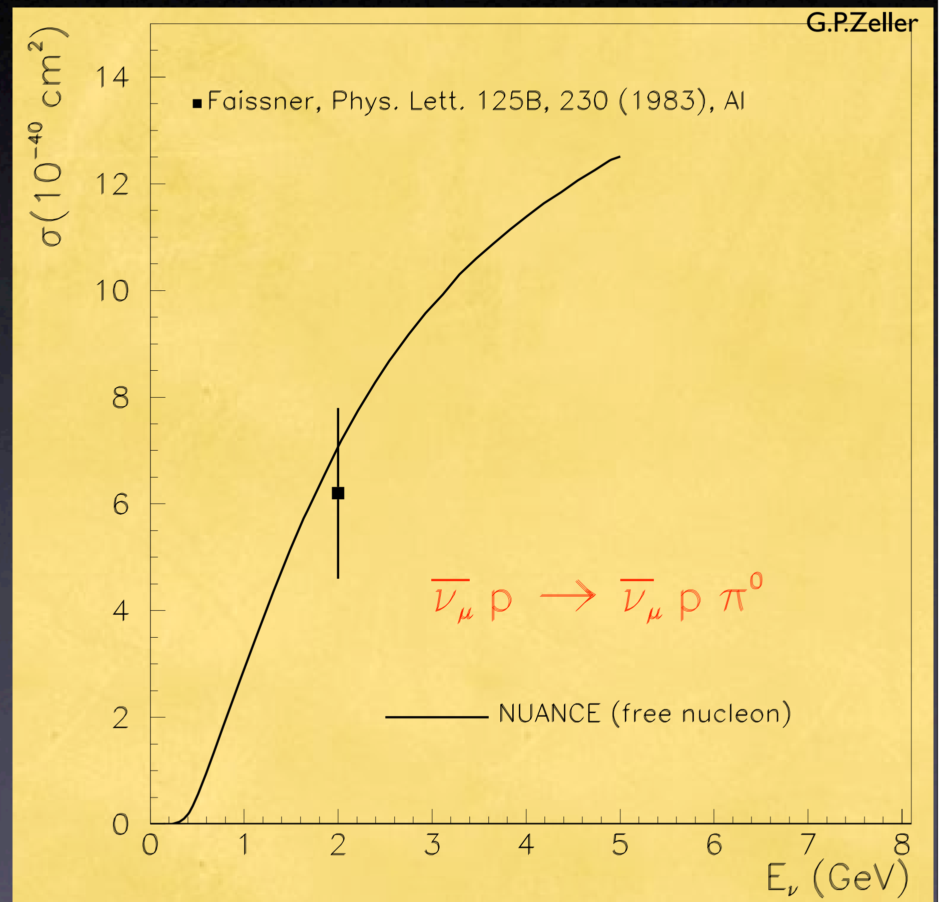


$\bar{\nu}_\mu$ CC QE Scattering

<E>	Experiment	target	date	#QE evts
2 GeV	Gargamelle	$C_3H_8CF_3Br$	1979	766
1.3 GeV	BNL	H_2	1980	13
16 GeV	FNAL	NeH_2	1984	405
6-7 GeV	SKAT	CF_3Br	1988	92
9 GeV	SKAT	CF_3Br	1990	159
5-7 GeV	SKAT	CF_3Br	1992	256
				1691

$\bar{\nu}_\mu$ NC π^0

- Only one measurement of $\bar{\nu}_\mu X \rightarrow \bar{\nu}_\mu N \pi^0 X$ to date[1]
  - 25% uncertainty at 2 GeV
- Important for $\bar{\nu}_e$ appearance searches
- Coherent production more apparent in antineutrino scattering



[1] This appeared as a footnote in Faissner et al., Phys. Lett. 125B, 230 (1983)

$\bar{\nu}_\mu$ CC1π^- Events

<E>	Experiment	target	date	#CC1π^- evts
1.5 GeV	Gargamelle	$C_3H_8CF_3Br$	1979	282
5-70 GeV	FNAL	H_2	1980	247
5-200 GeV	BEBC	D_2	1983	300
25 GeV	BEBC	H_2	1986	375
7 GeV	SKAT	CF_3Br	1989	120
				1324

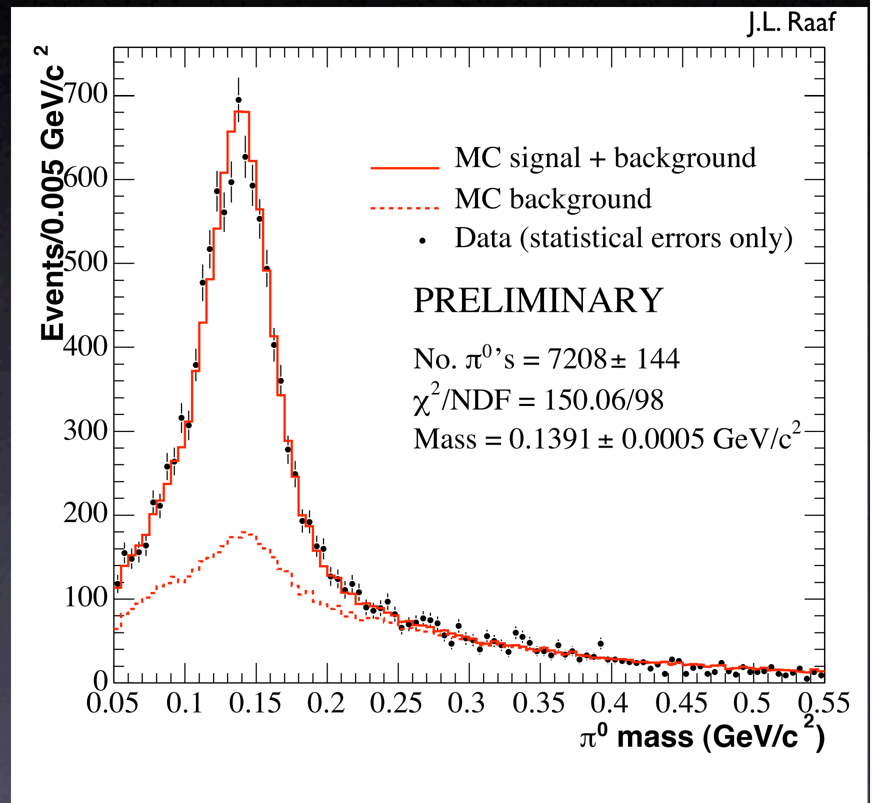
- Expectations for MiniBooNE
  - CCQE
  - NC$\pi 0$
  - $\nu\mu$ Disappearance
  - νe Appearance
- SciBar Detector in Booster Neutrino Beam

$\bar{\nu}_\mu$ CC QE Scattering

- Expect ~32,000 $\bar{\nu}_\mu$ CC QE interactions within fiducial volume for 2E20 POT
- MiniBooNE's current CC QE event selection:
  - Tank (>100) & veto (<6) PMT hit cuts
  - Fisher discriminant cu: event topology
    - Select single, μ-like ring
- Using CC QE event selection, ~19,000 total events
  - 75% pure QE (30% of those are WS)
  - May be improved with further $\bar{\nu}_\mu$ refinements
- Using WS constraints, expect to measure $\bar{\nu}_\mu$ CC QE cross section with ~20% uncertainty

$\bar{\nu}_\mu$ NC π^0

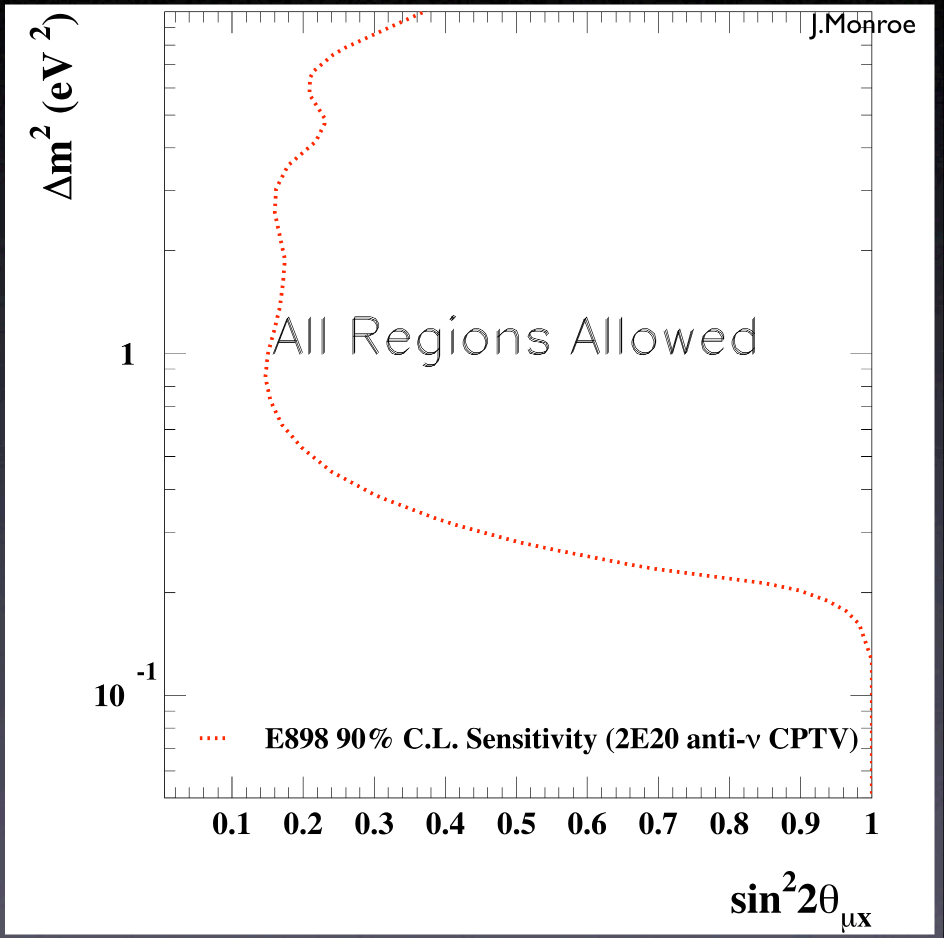
- Expect >5000 $\bar{\nu}_\mu$ NC π^0 events within fiducial volume for 2E20 POT
- MiniBooNE's event selection requires:
  - Tank (>200) & veto (<6) PMT hit cuts
  - Two-ring reconstruction
    - m_{π^0}>50 MeV/c^2, Eγ>40vMeV
- Application of event selection should yield
  - 1650 resonant events
  - 1640 coherent events (Rein & Sehgal)
  - ~1000 WS events



Reconstructed π^0 mass

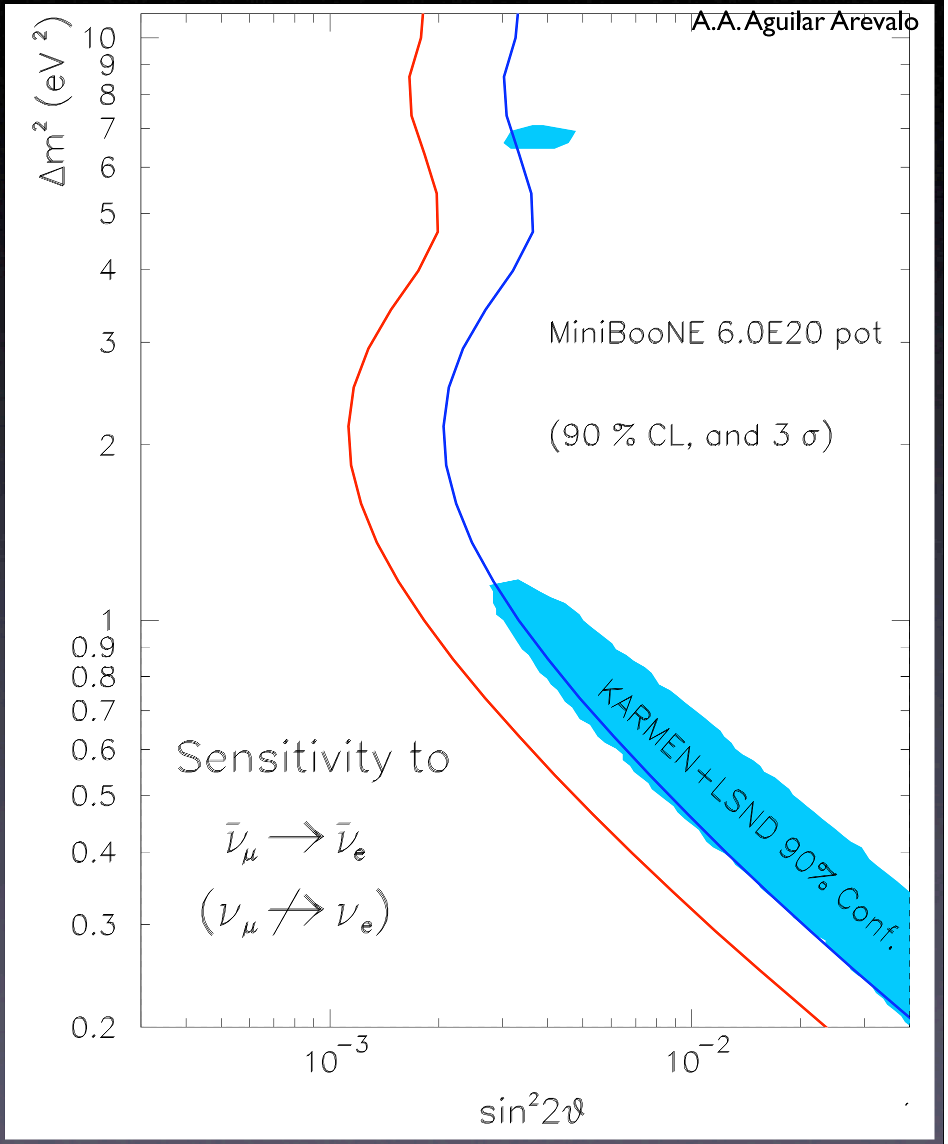
$\bar{\nu}_\mu$ Disappearance

- Oscillation appearance searches are sensitive to CPV, but not CPTV
  - Need disappearance search as well to distinguish between CPV and CPTV
- MiniBooNE can perform both searches
- Shown: CPT violating case
  - ν_μ do not oscillate, but $\bar{\nu}_\mu$ do oscillate
- Note: no existing limits on CPTV ν_μ disappearance



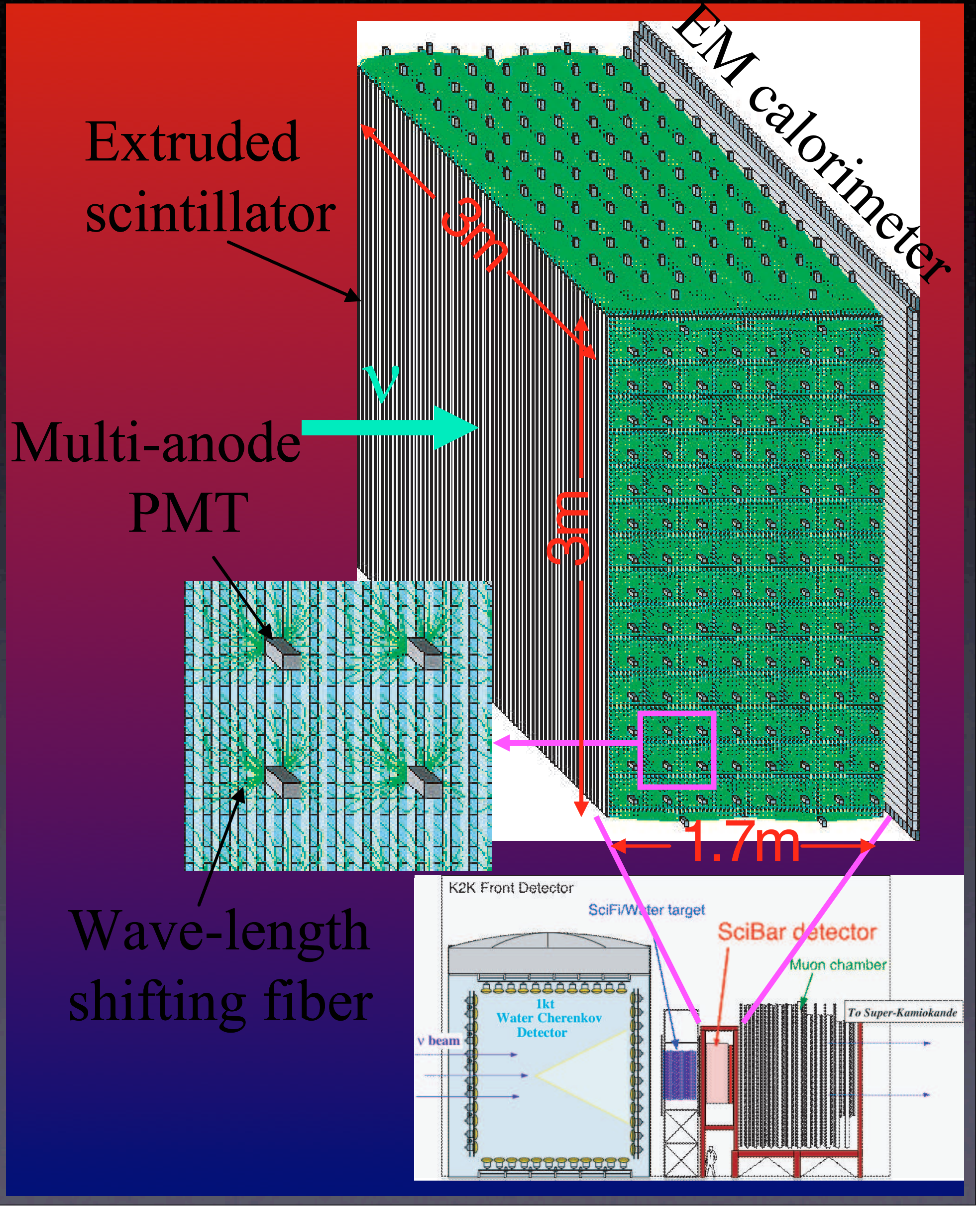
$\bar{\nu}_e$ Appearance

- Recall, LSND oscillations were seen in antineutrinos
    - $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$
    - True confirmation can only be made with antineutrino running!
- Shown: appearance sensitivity region for antineutrino oscillations in the case of no oscillations in neutrinos
    - Compare to LSND-KARMEN joint analysis allowed region
- Statistics limited!



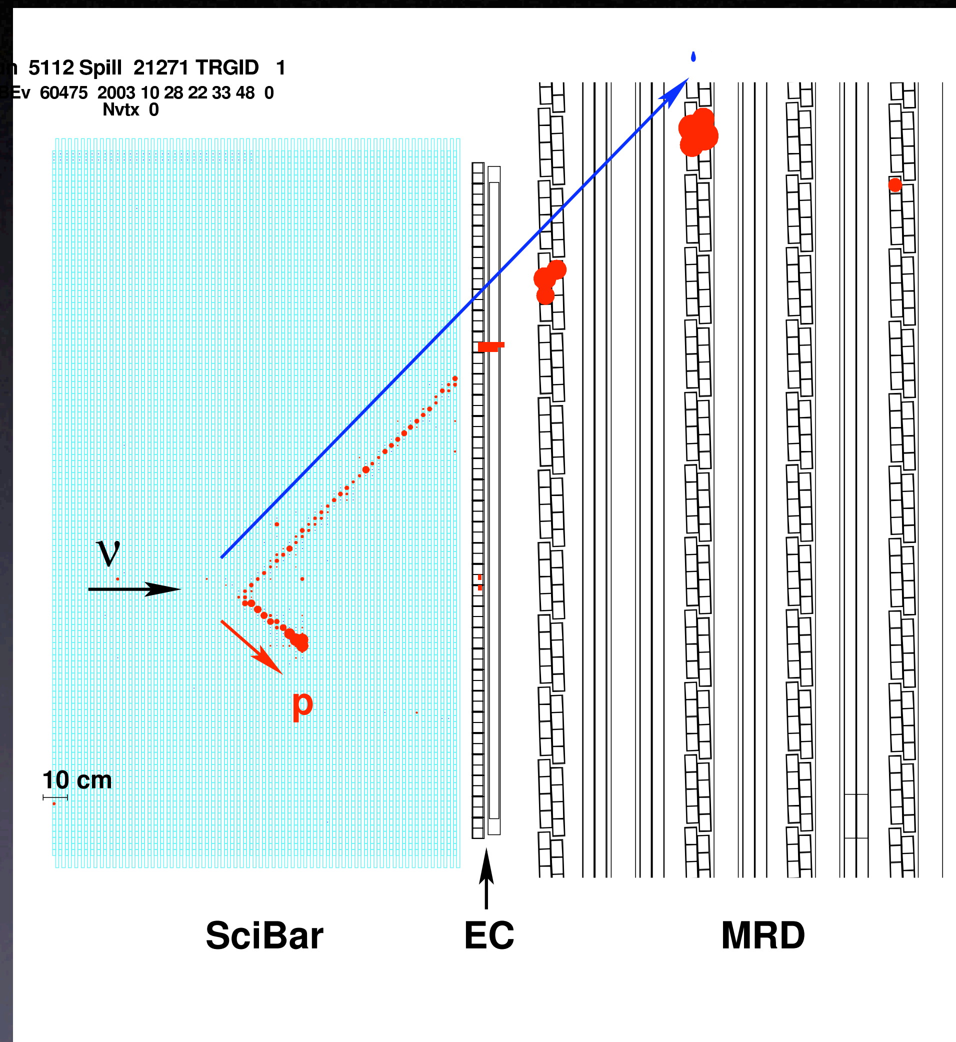
A Window of Opportunity

- K2K beam operations terminated in early 2005
- SciBar detector became available for use
- A new collaboration has formed to bring it to FNAL and place it in the Booster Neutrino Beam upstream of MiniBooNE: SciBooNE
- Subdetectors:
  - SciBar
  - Electron Catcher (EC)
  - Muon Range Detector (MRD)
- Already commissioned, well understood



BNB $\bar{\nu}_\mu$ CCQE in SciBar

- SciBar has the ability to detect the recoil proton track from CCQE events
- Can use this to constrain the WS BG in antineutrino running, including the energy spectrum!



SciBooNE Physics Goals

- SciBar Physics
  - Radiative Δ decay
  - Energy dependence of NCπ0 production
  - Exclusive π-p final states
- Leveraging MiniBooNE
  - WS BG constraints
    - $\nu_\mu, \bar{\nu}_\mu$ disappearance
  - Intrinsic ν_e flux
- Helping T2K
  - CC1π^+ σ - 5%
  - NCπ^0 σ - 10%
  - $\bar{\nu}$ σs

SciBooNE Schedule

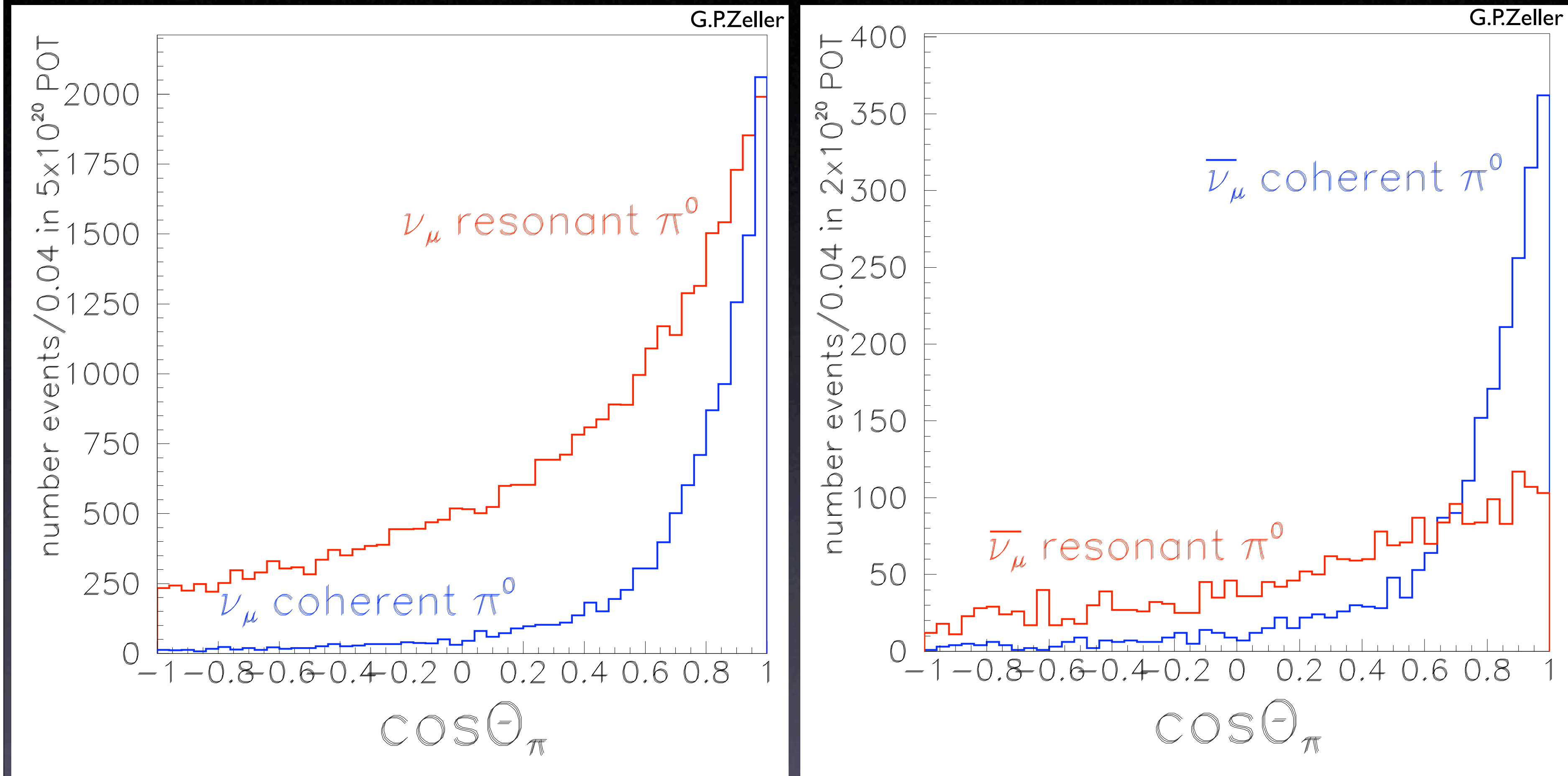
- K2K beam operations halted in March, 2005
- Submitted report on physics potential to Fermilab directorate 10 June, 2005
- Director's Review 11 October, 2005
- Will present proposal (P-954) to PAC in December, 2005
- Hope to have detector in place collecting beam data before end of 2006
  - Current construction schedule requires ~9 months

Conclusions

- MiniBooNE can open up the antineutrino cross section landscape with just one year of data
- We have developed several novel techniques to constrain the overall level of WS BGs
- Approved to run through end of 2006
  - Will decide when to switch to antineutrino mode mid-November
- SciBooNE: collaboration to bring SciBar to BNB

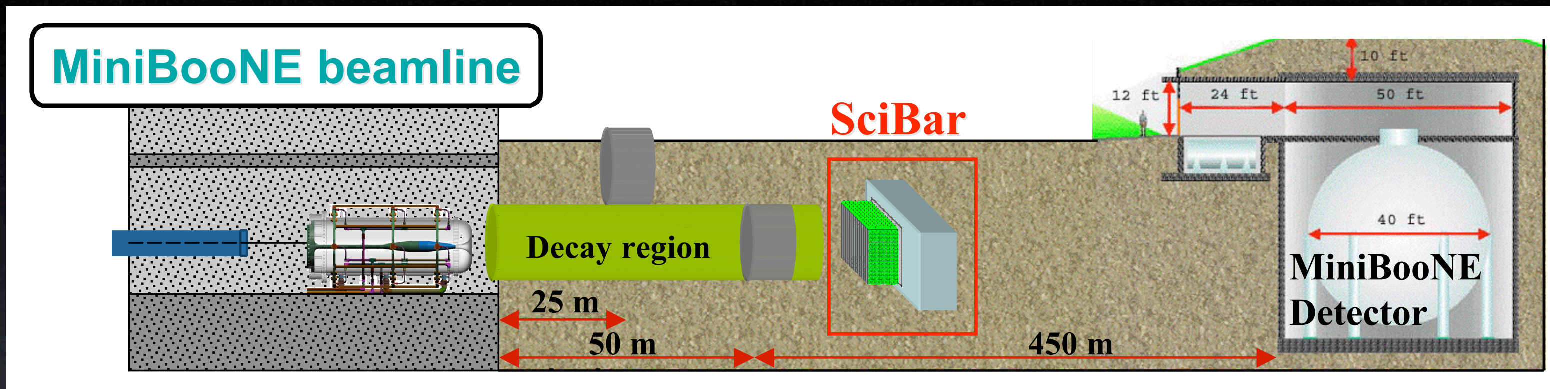
- MiniBooNE antineutrino running:
  - “Addendum to the MiniBooNE Run Plan: MiniBooNE Physics in 2006”
  - http://www-boone.fnal.gov/publicpages/loi.ps.gz
- SciBar at BNB
  - “Bringing the SciBar Detector to the Booster Neutrino Beam”
  - http://home.fnal.gov/~wascko/scibar.pdf

$\bar{\nu}_\mu$ NC π^0



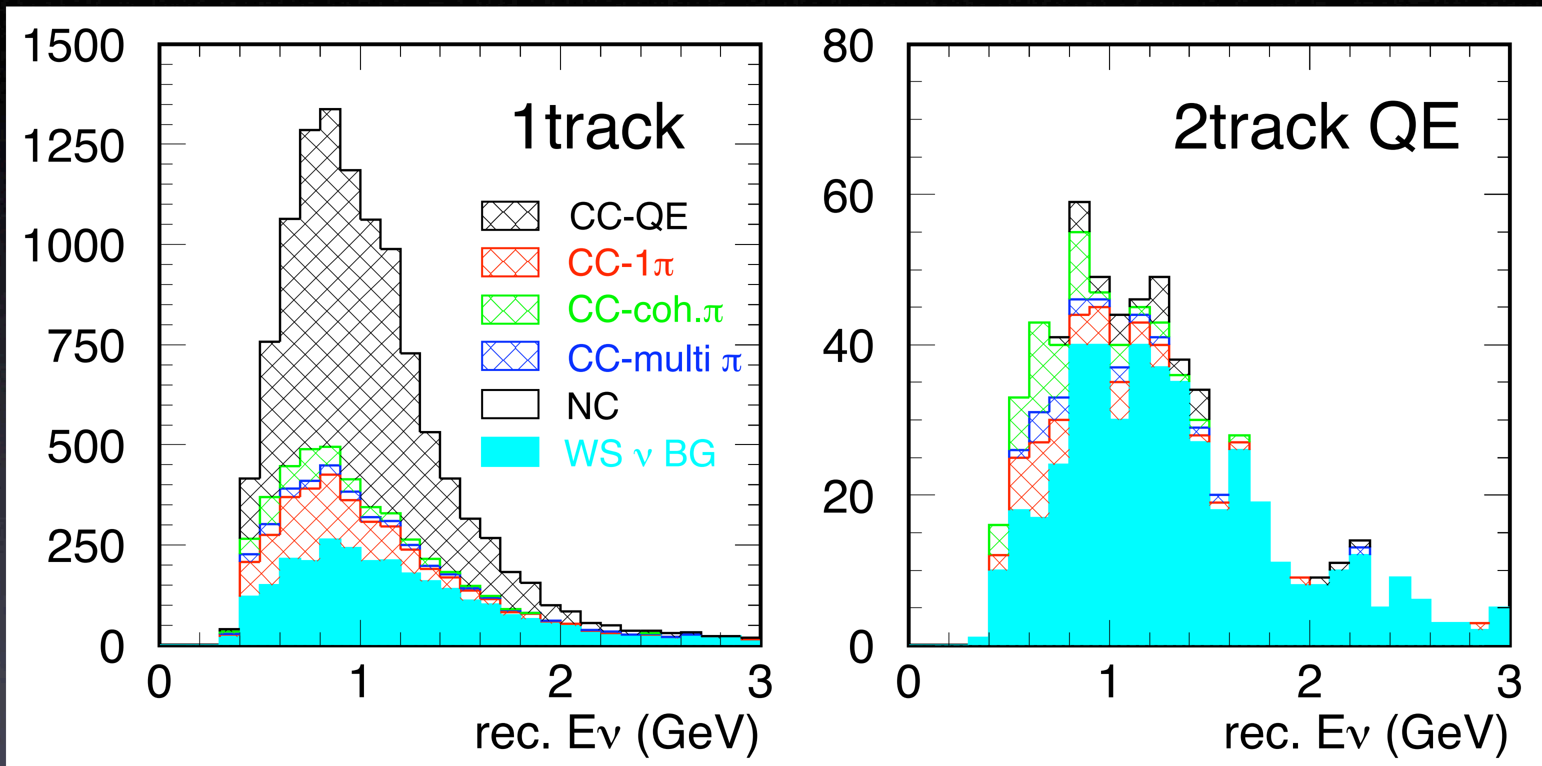
- Given the K2K coherent CC1π search, antineutrino running should be very interesting! (And very obvious.)

Experimental Setup



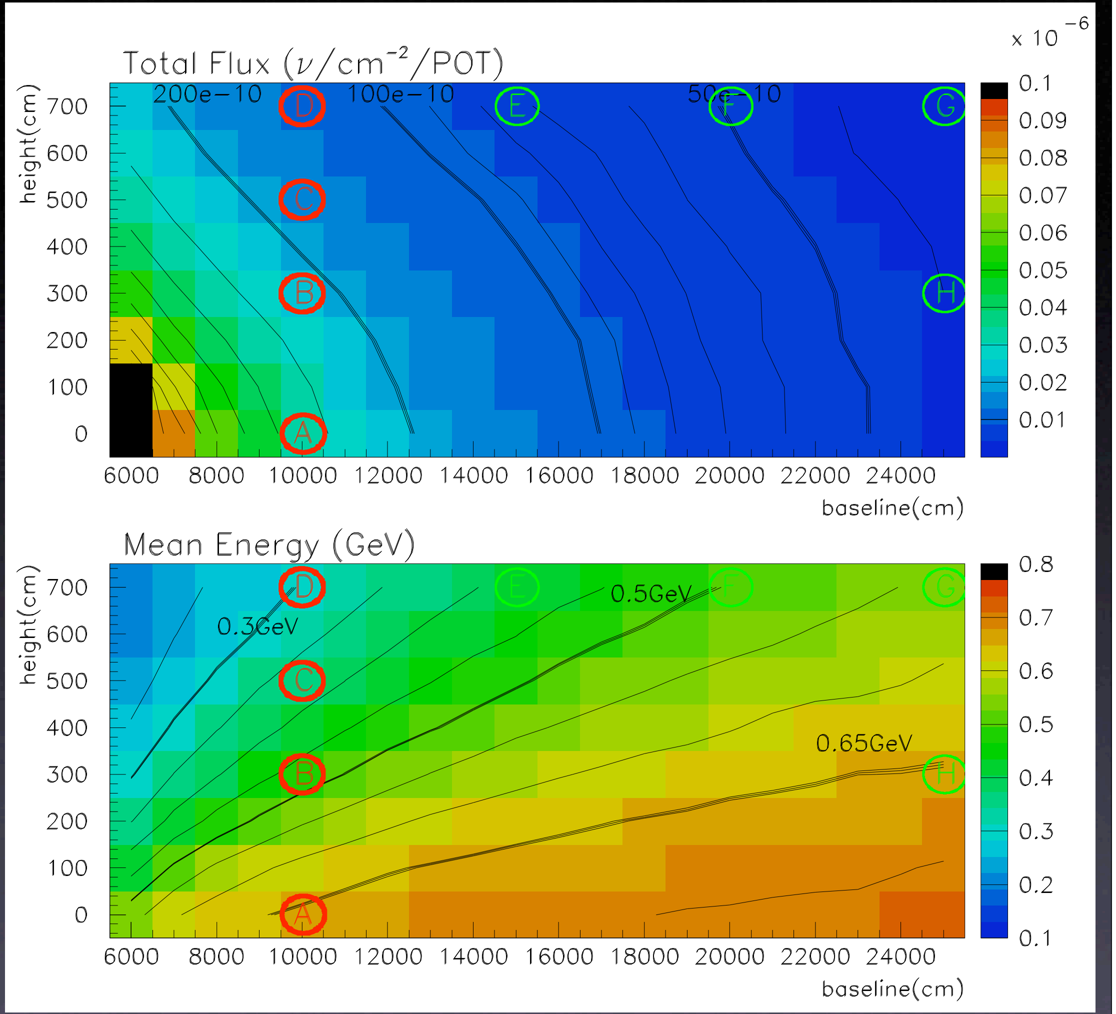
- Place SciBar on-axis 100 m from target
- Bring SciBar and EC from Japan
- Assemble MRD from salvaged parts from old fixed-target experiments at FNAL

BNB $\bar{\nu}_\mu$ CCQE in SciBar



- 1-track/2-track studies allow extraction of energy spectrum of WS BGs
- Improves cross section and oscillation measurements!

- Studied several detector locations to maximize physics output
- Balance neutrino flux and spectrum, event rates, and cost
- Studied 8 locations in detail
- On-axis location has best physics potential



Total ν flux and mean energy in BNB for different detector locations

- As off-axis angle increases:
  - Flux and mean energy decrease
  - WS fraction increases
- These effects conspire to dilute the effectiveness of the WS BG constraint
- On-axis is the best option